A database for galaxy evolution modeling

Claus Leitherer, Danielle Alloin, Uta Fritze-V Alvensleben, John S. Gallagher, John P. Huchra, Francesca Matteucci, Robert W. O'Connell, John E. Beckman, Eduardo Bica, Catherine Boisson, et al.

A Database for Galaxy Evolution Modeling

Claus Leitherer[1], Danielle Alloin[2], Uta Fritze-v. Alvensleben[3], John S. Gallagher[4], John P. Huchra[5], Francesca Matteucci[6], Robert W. O'Connell[7], John E. Beckman[8], Eduardo Bica[9], Catherine Boisson[10], Charles Bonatto[9], Gregory D. Bothun[11], Alessandro Bressan[12], Jean P. Brodie[13], Gustavo Bruzual[14], David Burstein[15], Nelson Caldwell[16], Emilio Casuso[8], Miguel Cerviño[17], Stéphane Charlot[18], Miguel Chavez[6], Cesare Chiosi[12], Carol A. Christian[1], Richard Dallier[10], Sonya Delisle[19], Angeles I. Díaz[20], Michael A. Dopita[21], Ben Dorman[22], Michael N. Fanelli[22], Michel Fioc[18], María Luisa García-Vargas[23], Jeffrey D. Goldader[1], Eduardo Hardy[19], Timothy M. Heckman[24], Jorge Iglesias[8], Pascale Jablonka[10], Monique Joly[10], Lewis Jones[25], Ariane Lançon[26], Thibault Lejeune[26], André Maeder[27], Maria Lucia Malagnini[28], J. Miguel Mas-Hesse[17], Georges Meynet[27], Mercedes L. Mollá[20], Carlo Morossi[29], Joy S. Nichols[22], Knut J. R. Ødegaard[30], Robert J. Panek[22], Joel Wm. Parker[22], Miriani G. Pastoriza[9], Reynier Peletier[8], Carmelle Robert[19], Brigitte Rocca-Volmerange[18], Daniel Schaerer[1], Alex Schmidt[31], Henrique R. Schmitt[1], Robert A. Schommer[32], Werner Schmutz[33], Margarida Serote Roos[10], Grażyna Stasińska[10], Ralph S. Sutherland[21], Rosaria Tantalo[12], Peeter Traat[34], Alexandre Vazdekis[8], Nolan R. Walborn[1], Guy S. Worthey[35], & Chi-Chao Wu[1]

[1] Space Telescope Science Institute, 3700 San Martin Drive, Baltimore, MD 21218

[2] Service d'Astrophysique, CEA Saclay, F–91191 Gif-sur-Yvette, France

[3] Universitätssternwarte Göttingen, Geismarlandstr. 11, D–37083 Göttingen, Germany

[4] Dept. of Astronomy, Univ. of Wisconsin-Madison, 5534 Sterling, 475 North Charter St., Madison, WI 53706

[5] Harvard-Smithsonian Center for Astrophysics, 60 Garden St., MS20, Cambridge, MA 02138-1516

[6] SISSA, Via Beirut 2-4, I–34013 Trieste, Italy

[7] Univ. of Virginia, Dept. of Astronomy, P.O. Box 3818, Univ. Station, Charlottesville, VA 22903

[8] IAC, Via Lactea s/n, La Laguna, E–38200 Santa Cruz de Tenerife, Spain

[9] Universidade Federal do Rio Grande do Sul, IF, CP 15051, Porto Alegre 91501–970, RS, Brazil

[10] Observatoire de Paris/Meudon, URA 173 CNRS, F–92195 Meudon Principal Cedex, France

[11] Univ. of Oregon, Dept. of Physics, 120 Willamette Hall, Eugene, OR 97403

[12] Univ. of Padova, Department of Astronomy, Vicolo dell'Osservatorio 5, I–35122 Padova, Italy

[13] Univ. Of California, Lick Observatory, Santa Cruz, CA 95064

[14] CIDA, Apartado Postal 264, Mérida, 5101-A, Venezuela

[15] Arizona State Univ., Dept. of Physics & Astronomy, Tempe, AZ 85287-1504

[16] Steward Observatory, Univ. of Arizona, Tucson, AZ 85721

[17] LAEFF, POB 50727, E–28080 Madrid, Spain

[18] Institut d'Astrophysique, 98bis Bd Arago, F–75014 Paris, France

[19] Université Laval, Departement de Physique, Ste-Foy, Quebec, G1K 7P4, Canada

[20] Univ. Autón. de Madrid, Dep. de Física Teórica, Facultad de Ciencias, C-XI, Cantoblanco, E–28049 Madrid, Spain

[21] Mt. Stromlo Observatory, Private Bag, Weston Creek P.O., ACT 2611, Australia

[22] Laboratory for Astronomy & Solar Physics, Code 681, NASA/Goddard Space Flight Center, Greenbelt, MD 20771

[23] IUE Observatory Villafranca del Castillo, Apartado 50727, E–28080 Madrid, Spain

[24] Johns Hopkins Univ., Bloomberg Center for Physics and Astronomy, 3400 North Charles St., Baltimore, MD 21218

[25] Univ. of North Carolina, Phillips Hall – CB#3255, Dept. of Physics and Astronomy, Chapel Hill, NC 27599-3255

[26] Observatoire de Strasbourg, 11 rue de l'universite, F–67000 Strasbourg, France

[27] Observatoire de Genéve, CH–1290 Sauverny, Switzerland

[28] Department of Astronomy, Univ. of Trieste, Via Tiepolo, 11, I–34131 Trieste, Italy

[29] Osservatorio Astronomico di Trieste, Via Tiepolo, 11, I–34131 Trieste, Italy

[30] Univ. of Oslo, P.O. Box 1029 Blindern, N–0315 Oslo, Norway

[31] Universidade Federal de Santa Maria, Dep. de Matemática/NEPAE, Faixa de Camobi, Santa Maria BR-97100, RS, Brazil

[32] CTIO, Casilla 603, La Serena, Chile

[33] Institute of Astronomy, ETH Zentrum, CH–8092 Zürich, Switzerland

[34] Tartu Astrophysical Observatory, Tähetorn krt. 1, Toomemagi, EE–2400 Tartu, Estonia

[35] Univ. of Michigan, 834 Dennison, Dept. of Astronomy, Ann Arbor, MI 48109-1090

Received ______________________; accepted ______________________

Submitted to PASP

ABSTRACT

This paper represents a collective effort to provide an extensive electronic database useful for the interpretation galaxy properties. A broad variety of empirical and theoretical data are discussed and made available on a CD-ROM published in conjunction with this article.

Several empirical stellar libraries are part of this database. They cover the ultraviolet spectral range observed with IUE, optical data from different ground-based telescopes, and ground-based infrared data in the H band. Spectral type coverage depends on the wavelength, but is mostly complete for types O to M and luminosity classes V to I. A large metallicity range is covered as well.

Theoretical libraries of selected spectral indices of cool stars and of stellar continuum fluxes in the temperature range 2000 K to 50,000 K, as well as Wolf-Rayet energy distributions are presented.

Several libraries of star clusters and early-type galaxies have been selected for this database. We discuss an extensive set of empirical spectral templates covering the wavelength region from 1200 – 9800 Å, as well as narrow-band line indices in a large number of passbands. Bench-mark spectra of nearby galaxy for model tests are included as well.

We compiled numerous evolutionary models for stars of all mass ranges of interest, wide metallicity range, and for all evolutionary phases, including the pre-main-sequence phase. The majority of the models has been computed by the Geneva and Padova groups.

Evolutionary synthesis models computed by several independent groups are made available. They can be applied to old and young systems, and are optimized with respect to different aspects of input physics. The model predictions include stellar (colors and magnitudes) and nebular (emission-line fluxes) properties.

Finally we present photoionization models to be used for the interpretation of active galactic nuclei and young star-forming galaxies.

The community is encouraged to make use of this electronic database and to perform a critical comparison between the individual datasets.

Subject headings: astronomical databases: miscellaneous — stars: evolution — stars: fundamental parameters — galaxies: evolution — galaxies: fundamental parameters — galaxies: stellar content

1. Overview

Modeling the stellar content of galaxies, by comparison either with theoretical or with empirical stellar libraries, has come a long way since the earliest interpretations of galaxy spectra as the superposition of spectra of stars were made. Scheiner (1899) was probably the first to make such an attempt. He realized the similarity between the spectrum of M31 and the solar spectrum and concluded that M31 is composed of solar-type stars and must therefore be a distant stellar system.

Since then, progress in observational techniques, theoretical modeling, and computing power has made it possible to perform detailed comparisons between observed and computed properties of even the most distant galaxies. In recent years the availability of large electronic databases has permitted the usage of more and more complex libraries and stellar models to make such comparisons. The goal of this paper is to provide an overview of existing empirical and theoretical libraries and evolution models and to make them available in the most convenient, user-friendly form.

The idea for this project came up during the organization of the conference *From Stars To Galaxies: The Impact Of Stellar Physics On Galaxy Evolution*, which was held in Porto Elounda Mare (Crete) in October 1995 (Leitherer, Fritze-v. Alvensleben, & Huchra 1996). Many of the participants felt the need for the publication of a homogeneous database which would contain many different libraries and models at the same place. The CD-ROM accompanying this paper is intended to fulfill this need.

The plan of the paper is as follows. Each of the authors contributed to the contents of the CD-ROM. We arranged the contributions into individual categories. Empirical stellar libraries are in Section 2. These data can be used in combination with existing population or evolutionary synthesis codes to compute spectral energy distributions and spectral features of stellar populations. These observed libraries are complemented by theoretical libraries (Section 3). In Section 4 we present empirical cluster and galaxy libraries. The purpose of these libraries is to serve as templates for comparison with other galaxies and/or as bench-mark tests for population and evolutionary synthesis models. A variety of stellar evolution models (including isochrones) are discussed in Section 5. Most of these models have been published elsewhere, and most are available electronically, but it will be convenient for the user to have all of them available on one CD-ROM. The majority of the models are suitable for implementation in synthesis codes. Evolutionary synthesis models for old and young systems are presented in Sections 6 and 7, respectively. These are essentially predictions for the evolution of the spectral energy distribution with time, based upon empirical and theoretical libraries and stellar evolution models. Section 8 gives examples for photoionization models. Three of the models are subsets of evolutionary synthesis models for young systems with emphasis on the nebular emission. One contribution provides shock models with an application to active galaxies.

In Table 1 we give a summary of the models discussed in this paper and included on the CD-ROM. All contributions within one section are in alphabetical order. The table lists the short title (column 1), the category as defined in the previous paragraph (column 2), the authors who submitted the data for inclusion on the CD-ROM (column 3), and the corresponding section in this paper (column 4). Column 5 gives the original reference of the work. *This reference should be used when a particular dataset is used or referred to, in order to give proper credit to the original authors.* If the CD-ROM as a database is quoted, the present paper should be referenced.

2. Empirical stellar libraries

Real galaxies consist of real stars. To make good spectral synthesis models we therefore need access to as large a panchromatic, well-calibrated database of empirical stellar energy distributions in as wide a range of environments as possible. Despite remarkable recent progress in computing beautifully detailed theoretical stellar energy distributions, it is essential to verify model spectra by comparison to real stars. Theoretical model grids certainly excel on the basis of convenience, homogeneity, and completeness. But they are probably best viewed as a means to interpolate across gaps in the empirical databases or to cautiously extrapolate to regimes not available in nearby stellar samples.

Considering their importance for integrated light studies of populations, the available empirical libraries of stellar spectra are somewhat sparse. Probably not more than 3000 flux-calibrated stellar spectra suitable for populations work have been published, and many surveys have restricted applicability — e.g. to only very old or very young systems. After these are broken down into temperature, gravity, and abundance bins (not to mention subclassification for various special features or anomalies), the resulting coverage for fiducial population types near the Sun is notably thin. The coverage for types relevant to other galactic environments (e.g. metal poor dwarf galaxies or "super" metal rich giant ellipticals) is, of course, much poorer.

Given the scope of the challenge, progress in assembling libraries over the last 25 years has been reasonably good, though clearly hampered by the lack of dedicated observing facilities and the disinclination of time allocation committees to support large-scale spectral surveys. Not accidental is the fact that many of the available libraries (as in this dataset) have emerged from the International Ultraviolet Explorer satellite, which is the nearest thing we have to a stable, dedicated, spectral survey facility.

Libraries have been constructed in a wide variety of formats. Most modern digital spectra have continuous wavelength coverage with spectral resolutions > 1000, yielding hundreds or thousands of independent spectral points. Continuous coverage is important for evaluating velocity smoothing effects. For population analysis, however, there are strong redundancies in integrated spectra, and it is usually advantageous to use a smaller set of discrete, well-calibrated spectral points which are as sensitive as possible to the important population parameters. To compensate for cosmic dispersion and random observational errors, data for individual objects are often combined to produce a representative group spectrum for a particular type of star. To reduce ambiguity in analyzing integrated light, it is important that signal-to-noise ratios in library spectra be made as large as practicable, with the goal of yielding S/N between 30 and 100 in the final, averaged group energy distributions.

This compilation includes only a few of the published empirical stellar spectral libraries. A summary of representative libraries published prior to 1992 is given in Fanelli et al. (1992), and more recent contributions are reviewed in the papers by Alloin (1996) and Olofsson (1996). Most of these are available in digital form. Overall coverage of the UV/optical/near-IR range ($0.12 - 1.0\mu$m) is reasonably good, but homogeneous data sets at shorter or longer wavelengths are quite limited. Stars with solar metal abundances are well sampled, but other metallicity regimes require a great deal more work. Users should be alert for inconsistencies within and between the various libraries; some of the known problems are discussed by Worthey (1994) and Silva & Cornell (1992).

2.1. Stellar libraries in the infrared and optical ranges *(Boisson, Dallier, Joly, & Serote)*

A very promising wavelength range not yet fully explored to study the stellar populations in the central part of galaxies is the near-IR range where a cool star spectrum peaks. The H window is particularly well designed for such a study, as the non-stellar contribution (mainly dust) is smaller in the H window than in the K window. Few stellar libraries are up to now available in the near-IR. Each of them being constructed for a specific purpose, they are generally not exhaustive. In particular, very few super metal rich (SMR) stars are included.

We present a sample of 37 stars from O to M for luminosity classes I, III, V, including 6 SMR stars, observed in the H band at medium resolution (Dallier, Boisson, & Joly 1996). Observations were conducted with the ISIS spectrograph at the CFHT and with IRSPEC at the ESO-NTT. The wavelength range covers 1.573 – 1.646 μm at the NTT (R = 1490 at 1.60 μm) and 1.578 – 1.642 μm at the CFHT (R = 2000 at 1.60 μm). Spectra are in relative fluxes, f_λ, normalized to 1 in the range 1.59290 – 1.59506 μm.

A library was also constructed in the visible wavelength range (Serote, Boisson, & Joly 1996) in order to expand, mainly by the inclusion of SMR stars, existing libraries.

Spectra of 21 stars in the range 4800 to 8920 Å, covering essentially the late spectral types, G, K, M and the luminosity classes I and III are available. Half of the stars are super metal rich. The spectra were obtained at a resolution of 1.25 Å using the Aurelie spectrograph, equipped with a linear array CCD-like detector, attached to the OHP 1.52 m telescope. The spectra of the 7 remaining stars, covering the region 5000 – 9783 Å at a resolution of 8.5 Å, were observed at the CFHT with the Herzberg spectrograph. The spectral types are F, G, K, M, and the luminosity classes III and V. Five stars are SMR. All spectra are in relative fluxes, f_λ, normalized to 100 at 5400 Å.

2.2. An ultraviolet group library *(Fanelli, O'Connell, Burstein, & Wu)*

This library of mean ultraviolet stellar energy distributions is derived from IUE spectrophotometry of 218 stars. The spectra cover 1230 – 3200 Å with a spectral resolution of ∼6 Å. They have been corrected for interstellar extinction and converted to a common flux and wavelength scale. Individual stars were combined into standard groups according to their continuum colors, observed UV spectral morphology, MK luminosity class, and metal abundance. The library consists of 56 groups: 21 dwarf (V), 8 subgiant (IV), 16 giant (III), and 11 supergiant (I+II) groups, covering O3 – M4 spectral types. A metal-poor sequence is included, containing four dwarf and two giant groups, as is a metal-enhanced sequence with a single dwarf, subgiant and giant group. More information on the library compilation and descriptions of the behavior of spectral indices characterizing the continuum and strong absorption features are given in Fanelli et al. (1992). Details of the provided spectra are given in the file *uvgrplib.hlp*.

2.3. The coudé feed spectral library *(Jones)*

Approximately 750 stars have been observed in the wavelength regions 3800 – 4500 Å and 4750 – 5450 Å at a resolution of about 2 Å FWHM. Interesting features included in those ranges are: Ca H & K, H8, Hϵ, Hδ, Hγ, G-band, Hβ, Mg_2, numerous strong Fe features, and some good CN indicators. Although the wavelength coverage is somewhat small and rather pathological, the spectral resolution provides so much more information than is available in other libraries, this set of spectra will be quite valuable for detailed spectral synthesis of galaxies. Atmospheric parameters covered are $-2.5 < [Fe/H] < +0.5$, spectral types O – M, and luminosity classes I – V.

2.4. An optical group library *(O'Connell)*

This library contains mean absolute spectral energy distributions for 48 common types of stars in the solar neighborhood and two globular clusters derived from spectrophotometry of 156 individual objects. The spectra include 46 selected wavelengths in the range 3300 – 10800 Å observed at 20 – 30 Å resolution. The spectral sequence provides measures of both the continuum and 21 selected absorption features (strong enough to be detectable in integrated light), including Balmer lines, individual metallic features and blends, and molecular bands. For objects with significant reddening, extinction corrections were made according to the Whitford law before combining the SED's. The standard error of the mean SED's (averaged over wavelength) of the well-observed groups ranges from 0.01 to 0.04 mags. In most cases, this reflects cosmic dispersion rather than photometric error. Coverage ranges from O5 to M8 spectral types and includes luminosity classes V, IV, III, and I. A small selection of metal poor and "super metal rich" stars is included. Further information on production of the library and on the behavior of continuum and line strength indices may be found in O'Connell (1973). Details of the provided spectra are given at the beginning of the ascii library file *ocgrplib.dat.*

2.5. An IUE high-dispersion library of O- and WR-stars *(Robert, Leitherer, & Heckman)*

We present IUE high-dispersion spectra of O- and WR-stars which are useful for spectral and evolutionary synthesis models of young star-forming regions. The library was described by Robert, Leitherer, & Heckman (1993) and Leitherer, Robert, & Heckman (1995).

The data presented here are for stellar groups having the same spectral type. There are 31 groups for O stars covering types O3 to O9.5 and luminosity classes V to I. The individual spectra were originally discussed by Howarth & Prinja (1989). In addition, four groups representing WNE-, WNL-, WCE-, and WCL-stars are included. They are based on St.-Louis' (1990) ultraviolet atlas of Wolf-Rayet stars. The identifications of the stars used to construct the 35 groups are in Table 1 of Robert et al.

The spectra have a resolution of 0.75 Å, cover the range 1205 – 1850 Å, and are normalized to a continuum level of 1.0. All library stars are located within a few kpc of the sun and have the corresponding ISM metallicity, i.e. solar, or somewhat below. Due to their nature as extreme Population I objects, the library stars are on sight lines of high interstellar gas column densities. Therefore the spectral features are a combination of stellar and interstellar lines. Care must be taken when interpreting the origin of a particular line. Detailed discussions have been given in the above quoted papers.

2.6. IUE atlas of O-type spectra from 1200 to 1900 Å *(Walborn, Nichols-Bohlin, & Panek)*

The IUE atlas of O-type spectra (Walborn, Nichols-Bohlin, & Panek 1985) contains 101 short-wavelength (SWP), high-resolution observations of 98 stars. They were selected on the basis of high-quality optical spectral classifications, in order to investigate systematically the behavior of the ultraviolet features, including the prominent stellar-wind profiles, and the degree to which they correlate with the optical types. The standard extracted spectrograms from the archive have been rebinned to a constant wavelength resolution of 0.25 Åand uniformly normalized. The plots are arranged in spectral-type, luminosity-class, and peculiar-object sequences. The results show a high degree of correlation between the ultraviolet features, both photospheric and stellar-wind, and the optical classifications for the great majority of the O-type stars.

2.7. IUE atlas of B-type spectra from 1200 to 1900 Å *(Walborn, Parker, & Nichols)*

The IUE atlas of B-type spectra (Walborn, Parker, & Nichols 1995) consists of short-wavelength (SWP), high-resolution data from the International Ultraviolet Explorer archive. It is designed to complement the widely used O-star atlas from the same source (Walborn, Nichols-Bohlin, & Panek 1985; see Section 2.6). The atlas presented here completes the OB natural group, extending to type B3 for the main sequence and giants, type B5 at class Ib, and B8 at Ia, which is also the most relevant domain for stellar-wind effects among normal B-type spectra. A number of hypergiants and chemically peculiar supergiants, particularly of types BN/BC (and including three of type O9.7 acquired since the O Atlas), are also displayed, as are two peculiar B-type dwarfs and one subgiant with enhanced winds.

A primary objective of this atlas is to chart in detail the systematic decline of the stellar winds in normal stars throughout their two-dimensional (spectral type, luminosity class) domain. As in the O-star atlas, which first demonstrated the strong correlation between the optical spectral types and the UV wind behavior in the majority of the stars, the principal selection criterion was the existence of high-weight optical spectral classifications, to ensure that a consistent reference frame of normal objects is derived. Altogether 86 images have been selected from the IUE archive for the atlas. The processing and presentation are as similar as possible to the O-star atlas, with the SWP data (1200 – 1900 Å range) rectified and rebinned to a uniform resolution of 0.25 Å.

3. Theoretical stellar libraries

3.1. A grid of Mg and Fe spectral indices *(Chavez, Malagnini, & Morossi)*

We present a grid of the absorption line spectral indices Mg_2, Mg_1, Mg b, Fe5270, and Fe5335, computed from high resolution theoretical spectra. The spectra are based on the CD-ROM release of Kurucz's model atmospheres (Kurucz 1993), and numerical codes. The grid covers the effective temperature range 4000 – 8000 K, surface gravity 1.0 – 5.0, and metallicities, [M/H], from -1.0 to $+0.5$.

The collection of indices represents an extremely valuable tool for detailed studies of old stellar populations within the context of populations synthesis (see, e.g., Chavez et al. 1996a). A detailed description of the models is given in Chavez et al. (1996b)

3.2. A grid of spectral indices for single stellar populations *(Chiosi & Tantalo)*

3.3. Calcium triplet synthesis *(García-Vargas, Mollá, & Bressan)*

We present theoretical equivalent widths for the sum of the two strongest lines of Calcium triplet, CaT, in the near-IR ($\lambda\lambda$8542, 8662 Å). We have used the spectral energy distributions presented by Bressan, García-Vargas, & Díaz in Section 7.1. The stellar CaT equivalent widths have been calculated according to the calibrations given by Díaz, Terlevich, & Terlevich (1989). The nebular contribution has been included. Tables with the synthetic line strengths, both stellar and nebular fluxes, at representative wavelengths in the ultraviolet, optical, near-IR and thermal IR are given. Details of the evolutionary synthesis code can be found in García-Vargas, Mollá, & Bressan (1996b).

We have calculated the CaT equivalent width single stellar populations (instantaneous burst, Salpeter-type IMF, $\alpha = 2.35$, $m_{low} = 1$ $M_\odot$, $m_{up} = 100$ $M_\odot$, M = 10^6 $M_\odot$), three metallicities (Z = 0.004, 0.008, and 0.02), and ages between log t = 6.00 [yr] and log t = 8.55 [yr] (with a logarithmic step in age of 0.05). Four models representative of the bulge population of age 5, 10, 12, and 15 Gyr are also included.

Several combined-population models have been computed with different mass percentages of young (2.5 – 4.5 Myr, capable to ionize), intermediate (around 9 Myr, rich in RSG) and old (bulge) populations. The equivalent width of Hβ in emission has also been synthesized. The tables contain sufficient information to allow the user to calculate any other required combination.

3.4. Theoretical energy distributions of cool stars *(Lejeune)*

We have assembled a grid of theoretical stellar atmospheres compiling a series of models published in the literature. The grid covers the following range of parameters: T_{eff}: 2000 – 50,000 K, log g: –1.02 to +5.5 and [M/H]: –3.5 to +1.0. To build this grid we have used: (i) Allard & Hauschildt (1995??) M dwarfs models; (ii) Kurucz (1995??) models; (iii) Bessel et al. (1991??) models for M giants. All the models have been transformed to the same wavelength and flux scale as the Kurucz (1995) models. This data set results are very valuable for the exploration of a large number of properties of individual stars or integrated stellar populations.

3.5. Theoretical energy distributions of Wolf-Rayet stars *(Schmutz)*

The latest generation of model atmospheres for Wolf-Rayet stars is successful in reproducing the observed line profiles and continuum energy distributions. Therefore it appears to be promising to use theoretical energy distributions of Wolf-Rayet stars for spectral synthesis. The need for the inclusion of realistic Wolf-Rayet model atmospheres in evolutionary synthesis models arises from the important contribution of Wolf-Rayet stars to the far-UV flux in sites of massive star formation. Wolf-Rayet stars can dominate the far-UV energy distribution for a few Myr during the evolution of a population of massive stars. Wolf-Rayet models suitable for inclusion in evolutionary synthesis are presented here.

The flux distribution of Wolf-Rayet star models are arranged in three grids (see Schmutz 1996). Grid 1 and 2 are intended for hydrogen-free Wolf-Rayet stars, with Grid 1 for stars with $T_{eff} < 90{,}000$ K and Grid 2 for those with higher temperatures. Grid 3 is for transition stars that still contain hydrogen in their atmospheres. The models of Grid 3 are line-blanketed whereas those of Grid 1 and 2 are pure helium models.

A description of the structure of the flux tables has been published in Schmutz et al. (1992) where directions for the use of the models are given as well.

4. Empirical cluster and galaxy libraries

By definition, the primary goals of most scientists working on population synthesis and galaxy evolution are to be able to measure fundamental properties of stellar populations in galaxies and other systems and predict the evolution of those properties in the cosmological model. The acid test of population models is to be able to reproduce real observations of galaxies and star clusters. Conversely, real data often form the basis for empirical models.

With those aims in mind, this section contains three observational data sets, two sets of spectra for galaxies and star clusters and one set of narrow band line indices in the Lick system, primarily for extragalactic globular clusters.

4.1. 1200 – 9800 Å templates of star clusters and early-type galaxies *(Bica, Alloin, Bonatto, Pastoriza, Jablonka, Schmidt, & Schmitt)*

We present a series of templates built from integrated spectra of star clusters and early-type galaxy nuclei for stellar population analyses. The spectral domain covered is from 1200 – 9800 Å, with a resolution in the range 7 – 17 Å. They have been collected by ourselves over several years at ESO, OHP, and CFHT in the near-ultraviolet, visible and near-infrared ranges, complemented by IUE spectra. For the visible range (∼3700 – 7000 Å), the star cluster spectra (Galactic open and globular clusters, and Large Magellanic Cloud clusters) were discussed by Bica & Alloin (1986a,b), for the near-infrared (∼7000 – 9800 Å) by Bica & Alloin (1987a), and finally for the near-ultraviolet (∼3150 – 4000 Å) by Bica, Alloin, & Schmitt (1994). M31 globular clusters are from Jablonka, Alloin, & Bica (1992). References for the galaxy spectra are Bica & Alloin (1987b) for the visible, Bica & Alloin (1987a) for the near-IR, whereas for the near-UV, they were observed in the same runs as the star clusters (Bica, Alloin, & Schmitt 1994), and will be discussed in a forthcoming paper. Galaxy templates in the visible and near-IR have been used in population syntheses, and those of star clusters have been used both to build up a grid of star cluster spectral properties as a function of age and metallicity, and for the visualization of the population syntheses (e.g., Bica 1988; Bica, Alloin, & Schmidt 1990). Star cluster templates in the far-UV (∼1200 – 3200 Å) were given in Bonatto, Bica, & Alloin (1995), whereas for early-type galaxies, they are discussed in Bonatto et al. (1996) and Bica et al. (1996). All spectra have been corrected for foreground reddening, as described in the references.

In the present collection we have merged the different wavelength ranges. The templates on the CD-ROM are one-dimensional files. Details on the files can be found in the respective papers.

4.2. Spectra of M32, NGC185, and NGC205 *(Hardy & Delisle)*

Only a handful of galaxies are sufficiently close to us that their stars can be resolved individually down to the level of an old or at least intermediate-age MS turn-off, even with HST. Thus, in only very few cases can we construct color-magnitude diagrams to sufficiently faint magnitudes that something approaching the full history of star formation in these galaxies can be reliably reconstructed from the observations. As soon as we leave the Local Group, spectral synthesis, in its different varieties, becomes the only technique that can be used to derive information on the stellar content of galaxies. Because of the intrinsic difficulty of the subject, its non-uniqueness, and its reliance on stellar evolutionary tools and spectral libraries, it is imperative that the predictions of spectral synthesis be tested on galaxies *for which the answer sought is known in advance or will become known soon through direct observations of their resolved components.* Among the very few galaxies suitable as test-benches are three M31 satellites, M32, NGC185, and NGC205, for which we provide here flux-calibrated spectral information (Delisle & Hardy 1996). These galaxies are probably of solar or sub-solar metallicity, but are well suited for most available stellar and SED libraries. In addition, at least NGC185 and NGC205, are sufficiently diffuse that very deep color-magnitude diagrams are possible.

These data will be useful for synthesizing the stellar populations of the above galaxies, for which high-spatial resolution observations will provide independent knowledge of such populations in the near future. In this way synthesis predictions could be confronted with independent results derived from color-magnitude diagrams.

The spectroscopic data furnished here are quite limited in spectral interval and resolution as well as in spatial coverage. They will have to be supplemented by observations conducted in the IR and UV range, and also with observations obtained at spectral classification resolution, i.e. at about 2 – 3 Å FWHM.

4.3. Narrow band spectral indices for globular clusters and galaxies *(Huchra, Brodie, Caldwell, Christian, Schommer, & Bothun)*

This is a collection of line indices in the Lick system (and others) for a collection of Galactic, M31, M33 and other globular clusters plus bright and dwarf galaxies observed primarily at the MMT over the period 1980 – 1992 by J. Huchra, J. Brodie, N. Caldwell, R. Schommer, C. Christian and G. Bothun. The paper describing this catalog of indices is published in Huchra et al. (1996). Table **??** lists the definition of the indices used.

The tables on the CD-ROM list the line indices and errors, multiple measurements for individual objects (plus dispersions and means) to give the reader a sense of the precision and accuracy of individual measures, and index measurements from higher dispersion spectra. Each of the index tables generally has two lines, the first are the index values and the second are the statistical (calculated from photon counts) errors. An estimate of the external error in each index can be gotten from the multiple measurements given.

5. Stellar evolution models

A general review of stellar evolution has been given by Chiosi, Bertelli, & Bressan (1992). The physics of massive star evolution is discussed in Chiosi & Maeder (1986).

The most widely used stellar evolution libraries are those computed by the Geneva and Padova groups. Both libraries are made available here. They cover a wide range in metallicity and include low-mass, intermediate-mass, and high-mass evolution. The libraries are discussed in Sections 5.1, 5.2, and 5.3. They are based on the most up-to-date input physics, such as OPAL opacities, stellar mass loss, mixing, convective overshooting, and rotation. Differences between the two libraries which are relevant for population synthesis exist. They result from different treatment of various input parameters, and from their observational and theoretical uncertainties. An example is the stellar mass-loss rate, which is varied by a factor of 2 in the Geneva models in order to study its effect on the evolutionary tracks. The influence of different stellar evolution models on evolutionary synthesis models of populations has been discussed by Charlot, Worthey, & Bressan (1996) and García-Vargas, Leitherer, & Bressan (1996a) for old and young populations, respectively.

Pre-main-sequence evolution has generally been ignored in evolutionary synthesis models. The Kelvin-Helmholtz timescale to reach the main-sequence was considered to be long in comparison with the evolutionary timescale of those stars relevant to the properties of the population. New models for massive stars take into account accretion during the pre-main-sequence evolution (Bernasconi, Section 5.3). The accretion time is much longer than the Kelvin-Helmholtz time, and this phase becomes relevant for a massive-star population.

Also included on the CD-ROM are stellar evolution models by Ødegaard. These models were calculated independently from Geneva and Padova and are useful for comparison (Section 5.4).

Most recently, attempts were made in stellar evolution models to relax the artificial separation between the stellar interior and the atmosphere. Combined stellar models are particularly relevant in advanced evolutionary stages of massive stars when strong winds invalidate the traditional assumption of a static, grey atmosphere. The first generation of these models has been computed by Schaerer (Section 5.5).

5.1. The Padova library of stellar evolution models *(Chiosi & Tantalo)*

We present an extensive set of isochrones, based upon the latest generation of Padova stellar evolution models. The isochrones range from 20 Gyr to a few Myr for six different chemical compositions, starting at Z = 0.0001 and Y = 0.23, up to Z = 0.1. They are scaled according to $\frac{dY}{dZ} = 2.5$. The isochrones are in the T_{eff} – log L plane, in several passbands of the Johnson system (UBVRIJHKLMN), a few of the HST system, and a few of the far-UV HST system.

We also give integrated magnitudes and colors (in the same systems as above) and line-strength indices for single stellar populations as a function of the age and chemical composition. Furthermore, we make the spectral energy distributions themselves available in order to allow users compute their own colors and other quantities of interest.

Finally we have prepared a library of select galactic models containing integrated spectral energy distributions, integrated colors, magnitudes, line-strength indices, etc., as a function of the age in the rest frame, together with the companion redshifted integrated spectral energy distributions at given H_0 and q_0.

5.2. The Padova isochrones and SSP models *(Chiosi & Tantalo)*

5.3. Update of Geneva library of stellar evolution models *(Meynet & Maeder)*

We present the complete set of stellar models computed by the Geneva group until now. The Geneva "package" on the CD-ROM contains:

- pre-main-sequence evolution with accretion (Bernasconi 1996);
- main-sequence (MS) and post-MS evolution in the range of 0.8 to 120 $M_\odot$ for:

  Z = 0.040, Y = 0.34 (Schaerer et al. 1993; SCMMS)

$Z = 0.020$, $Y = 0.30$ (Schaller et al. 1992; SSMM)

$Z = 0.008$, $Y = 0.264$ (Schaerer et al. 1993; SMMS)

$Z = 0.004$, $Y = 0.252$ (Charbonnel et al. 1993; CMMSS)

$Z = 0.001$, $Y = 0.243$ (Schaller et al. 1992; SSMM);

• horizontal branch (HB), post-HB and AGB star models for various Z and Y (Charbonnel et al. 1996; CMMS);

• models of stars with $M > 15\ M_\odot$ for all above (Z, Y) with mass-loss rates increased by a factor of 2 (Meynet et al. 1994; MMSSC);

• a code for calculating isochrones of different ages;

• complete tables of isochrones calculated for various Z and ages between 3×10^6 yr and 12×10^9 yr.

Work in progress includes (i) models of low-mass stars between 0.3 and 1.0 $M_\odot$ for various Z, with an up-to-date equation of state (Charbonnel 1996); (ii) models in the range 0.3 to 120 $M_\odot$ at $Z = 0.10$ (Mowlavi et al. 1996); and (iii) refined models of young starbursts (age $<$ 12 Myr), including also pre-MS evolution and providing the emergent spectrum predicted by complete stellar models (Schaerer & Bernasconi 1996). The results will be available in the near future.

A detailed discussion of the physical ingredients can be found in SSMM, CMMSS, MMSSC, and CMMS. Therefore only a brief summary is given here. (i) The new radiative opacities by the OPAL group have been used (Rogers & Iglesias 1992; Iglesias et al. 1992; Iglesias & Rogers 1993). (ii) At low T_{eff}, i.e., below 6000 K, radiative opacities by Kurucz (1991) also including the main molecular lines have been accounted for. (iii) The initial composition (Y, Z) has been chosen consistently with a relation of the form $Y = Y_p + \frac{dY}{dZ}\delta Z$, where Y_p is the primeval helium content and $\frac{dY}{dZ}$ is the relative helium-to-metal enrichment. Y_p is taken equal to 0.24 and $\frac{dY}{dZ}$ has been chosen equal to 3, except for $Z = 0.04$ where $\frac{dY}{dZ}$

was taken equal to 2.5. (iv) The mass-loss rates are taken as given by de Jager et al. (1988) for stars throughout the HR diagram, except the Wolf-Rayet stars. We adopt a scaling of mass-loss rates with metallicity as given by the models of Kudritzki et al. (1991), i.e. $\dot{M}$ is proportional to $Z^{0.5}$. For Wolf-Rayet stars, there is no indication yet for a dependence of $\dot{M}$ values on initial Z. However, we adopt the $\dot{M}$ versus mass relation found by Langer (1989) for WNE and WC stars, i.e. $\dot{M} = (0.6 - 1.00) \times 10^{-7}\ (M/M_{\odot})^{2.5}$ in solar masses per year, respectively. For WNL, the average mass-loss rate of 4×10^{-5} is adopted (cf. Conti 1988). These mass-loss rates were enhanced by a factor of 2 during the pre-W-R and the WNL phases in MMSSC. (v) Extensive comparisons of models and observations have suggested the presence of moderate overshooting of about 0.2 H_p. (vi) The detailed treatment of the partial ionization for the heavy elements has been included. (vii) The optically thick wind of W-R stars is treated in the framework of the modified Castor, Abbott, & Klein theory (Castor, Abbott, & Klein 1975; Kudritzki et al. 1989). This enables us to satisfactorily calculate the T_{eff} and radii of W-R stars.

5.4. Models for the evolution and nucleosynthesis of massive stars *(Ødegaard)*

Detailed nucleosynthesis calculations of very massive stars up to advanced stages have been performed. The computations include a nuclear network with 174 species linked by 1742 nuclear reactions. The computations have been done with a dynamical stellar evolution code and include semi-convection and overshooting. The large nuclear network and the diffusion equation are solved at each time step. A more detailed description of the computations can be found in Ødegaard (1996a,b)

Surface abundances of 95 selected species from H to Ge are presented. We also give the evolutionary tracks of the stars. The model predictions include stellar mass, mass-loss rate, luminosity, T_{eff}, core temperature and density, mass of convective core, abundances of ^{4}He, ^{12}C, and ^{16}O in the core, and the accumulated mass loss of each nuclear species.

5.5. Combined structure and atmosphere models for massive stars *(Schaerer)*

The recent "combined stellar structure and atmosphere models" (hereafter *CoStar*) for massive stars consistently treat the entire mass losing star from the stellar interior to the outer region of the stellar wind (see Schaerer et al. 1996a,b). In particular, the atmosphere calculations treat H and He in non-LTE, and include line-blanketing in a spherically expanding atmosphere.

We have calculated an extensive set of tracks with initial masses between 20 and 120 $M_\odot$ at Z = 0.02 (solar metallicity) and Z = 0.004 (0.2 solar). Details are given in Schaerer (1996). We selected 27 models providing a good description of these sequences. They cover the entire parameter space of O3 – B0 stars of all luminosity classes (see Schmutz 1996 for similar calculations for W-R stars). Here we provide the theoretical continuous spectral energy distribution predicted by our *CoStar* models. The spectral range covers the EUV to far-IR domain.

Our calculations represent the first non-LTE line-blanketed models, which also account for the stellar wind and cover dwarf to supergiant stages of O3 to B0 stars. Of special interest are the ionizing fluxes, which are strongly affected by non-LTE and wind effects (cf. Schaerer et al. 1996b, Schaerer 1996). Models of H II regions calculated with the present spectra are provided by Stasińska (see Section 8.4). The *CoStar* spectra are also suited for synthesis models of young stellar populations.

6. Evolutionary synthesis models: old systems

In the early days of galaxy evolution modeling old stellar populations such as, e.g., elliptical galaxies, seemed much easier to describe than, for instance, young populations like spiral, irregular or starburst galaxies. The reasons were that from optical and near-IR broad-band colors early type galaxies (Es and S0s) seem to form a very homogeneous class of objects, gaseous emission as well as dust absorption are unimportant as compared to late type or starburst galaxies. With the extension of the accessible spectral range to the UV, X, sub-mm, and radio regions, as well as with the availability of higher spatial resolution for spectroscopy, this situation has changed dramatically. E.g., in the UV elliptical galaxies show a variety of spectral properties that keep challenging stellar evolution models, many of the former "old, red and dead" E/S0 galaxies nowadays show evidence for intermediate age populations or at closer look even reveal some central ongoing star formation. Cold gas detected near the centers of several E/S0 galaxies as well as hot gas seen as X-ray coronae prove that these galaxies are not entirely gas-free. The classical picture of a monolithic initial collapse scenario for the formation of ellipticals is questioned by detections of intermediate age sub-populations, peculiar core kinematics and of obvious old spiral-spiral merger remnants well advanced on their way to becoming E/S0 galaxies.

The optical and near-IR light of old stellar populations is dominated by low-mass stars in their late and luminous stellar evolutionary phases. The correct description of their stellar evolutionary tracks including the lifetimes of the various stages are of crucial importance. We know by now that the range of stellar metallicities in elliptical is large. While low to average luminosity ellipticals reveal significantly subsolar abundances in their integrated spectra the nuclear regions of high luminosity Es contain a significant population of high metallicity stars.

The method of *Population Synthesis* uses some minimization scheme to isolate from a complete library of observed or theoretical stellar spectra those constituents and their respective proportions that contribute to the spectral energy output of an observed galaxy. The use of isochrone spectra instead of individual star spectra makes sure that some form of IMF is realized in the solution. If distinctive spectral features are used this method can give a very precise — though not necessarily unique — *status quo* description of a composite stellar population. *Evolutionary Synthesis* aims at modeling the complete evolutionary path of a stellar system to the presently observed state. Assuming some kind of star formation history, the spectral evolution of a galaxy is followed from the birth of the first stars, thus directly offering cosmological applications. Pieces of input physics can either be a complete set of stellar evolutionary tracks, an IMF, and a library of color calibrations or stellar spectra. Simple Stellar Populations (= single burst and single metallicity) and early-type galaxies with their discontinuous or strongly declining star formation histories in general lead to luminosities, colors, and SEDs strongly fluctuating in time. Two approaches are used to cure this problem, one keeps the IMF as a free parameter and smooths the resulting luminosity and color evolution in an appropriate way, the other uses smoothly interpolated isochrones which already incorporate some IMF. Every composite stellar population with any kind of star formation history, as e.g. a burst of given strength at some stage of evolution, can be expanded into a series of SSPs of different ages.

Some of the models presented here also follow the chemical enrichment history of composite stellar populations and use stellar tracks and spectra for various metallicities to consistently account for the enrichment history of successive stellar generations. Open problems here are the poorly known He-to-metal evolution (dY/dZ) and the influence of non-solar abundance ratios.

6.1. A library of galaxy spectral evolutionary models *(Bruzual & Charlot)*

Isochrone synthesis spectral evolution models for simple stellar populations of metallicity Z = 0.0004, 0.004, 0.008, 0.02, 0.05, and 0.10 are included in this contribution. The models are based in the Padova group evolutionary tracks and the Lejeune et al. model atmosphere compilation described in Section 3.4. The evolving spectra include the contribution of the stellar component in the range from the EUV to the FIR; the age varies from 0 to 20 Gyr and various IMF's are considered. For the Z = 0.02 case, models built from empirical stellar libraries of low and high resolution (in the optical range) are included. Programs are provided to compute composite stellar populations from the included single stellar populations. This is the natural extension and update of the models by the same authors that are currently available (for solar metallicity only).

A detailed description of this models can be found in Bruzual & Charlot (1996).

6.2. Library of spectral evolution for single stellar populations *(Chiosi & Tantalo)*

6.3. Spectro-photometric models of elliptical galaxies *(Chiosi & Tantalo)*

6.4. Ultraviolet spectra for old stellar populations *(Dorman)*

We present synthetic spectra for older stellar populations for the wavelength range $1200 < \lambda < 6000$ Å. The models are generated from isochrones used by Dorman, Rood, & O'Connell (1995) in their study of integrated UV colors of old stellar populations. They cover the age range 2 – 20 Gyr, and metallicity range $-2.3 <$ [Fe/H] < 0.6. Also supplied are model spectra for the advanced stages of evolution. The data we provide give the integrated spectra of HB models from the EHB to the red HB, from the HB models of

Dorman, Rood, & O'Connell (1993). We also give synthetic spectra for integrated P-AGB components. All synthetic fluxes are computed with the nearest metallicity Kurucz (1993) model stellar fluxes, and by assuming a Salpeter initial mass function.

We provide the components separately so that models with any desired HB morphology may be constructed. Details of how to combine these spectra into astrophysically consistent models (satisfying the fuel consumption theorem by fixing the birthrate of HB stars) can be found in Dorman et al. (1995).

6.5. Spectral evolution from the far-UV to near-IR *(Fioc & Rocca-Volmerange)*

A new model based on an algorithm of integration available for isochrones and isomasses has been built by using the coherency of the photometric system of Bessel & Brett (1988) and a unique calibration on the whole wavelength range (Fioc & Rocca-Volmerange 1996).

The synthetic energy distributions are applicable to 10 different galaxy types along the Hubble sequence and cover 220 Å to 5 μm. Several different IMF's are considered. We also include time-dependent extinction factors and nebular components. Cosmological and evolution corrections are accounted for as well.

Output products are synthetic colors in numerous filters over a Hubble time. Most of these output data will be described in detail by Rocca-Volmerange et al. (in preparation).

6.6. Grid of galaxy spectra from evolutionary synthesis *(Fritze-v. Alvensleben)*

Using a new set of stellar evolutionary tracks from Geneva we have computed an extensive grid of galaxy spectral energy distributions. Datasets available are:

- simple stellar populations for five different metallicities;
- a Hubble Sequence of galaxies E, S0, Sa, Sb, Sc, Sd for solar metallicity;
- a Hubble Sequence of galaxies E, S0, Sa, Sb, Sc, Sd calculated in a chemically consistent way, i.e. following stars of successive generations on stellar tracks appropriate for their initial chemical composition.

Each file contains luminosities in UBVRIK and some stellar absorption indices for each system. Also included are spectra at some of the time. Stellar input spectra are from (IUE + Gunn & Stryker + Persson) for solar metallicity models, and from Kurucz (1993) for models having non-solar metallicities.

6.7. Grids of theoretical evolutionary spectra of stellar populations *(Traat)*

We present numerous sets of tables of theoretical spectra with fine age coverage of stellar populations for a wide range of chemical compositions, initial mass functions and star formation rates, based on the latest stellar evolutionary tracks and model atmospheres. For hotter stars, Kurucz's (1993) model atmospheres were adopted. In the cool star region we used newly computed far more reliable Uppsala atmospheres. The grids are superior to previous ones also by the inclusion of the latest tracks of low-mass stars down to the mass limit to reach the main-sequence.

6.8. A spectrophotometric population synthesis library for old stellar systems *(Vazdekis, Casuso, Peletier, & Beckman)*

We present the results of a new spectrophotometric stellar population synthesis model designed to study old stellar systems by Vazdekis et al. (1996). The model incorporates the latest stellar spectral libraries and the new isochrones of the Padova group and transformed to the observational plane by our own method. The model provides six optical and near-infrared colors and line indices for 25 absorption lines. It can synthesize single age, single metallicity stellar populations or incorporate a complete sequence of chemical evolution, following the evolution of a galaxy from an initial gas cloud to the present time. Our goal here is to present tables with the obtained synthetic colors and line-strengths. For a simple single-age, single-metallicity stellar population model we vary the metallicity, the age and the IMF shape and its slope. For our full chemical evolutionary population synthesis model we vary the SFR regime, the age and the IMF shape.

6.9. Evolutionary population models for early-type galaxies *(Worthey)*

The Worthey (1994) evolutionary population models give integrated UBVR$_C$I$_C$JHKLL′M colors and magnitudes, SBF magnitudes, spectral energy distributions, and Lick/IDS spectral index strengths for populations of arbitrary age, and (assumed scaled-solar) abundance [Fe/H]. The ages range from 1 to 18 Gyr, and abundances from −2.0 to +0.5 dex. Helium abundance Y is a free parameter. The underlying stellar evolution is that of VandenBerg (VandenBerg 1985, VandenBerg & Bell 1985, VandenBerg & Laskarides 1987). The stellar fluxes used to compute integrated flux are mostly theoretical (Kurucz 1992a, Bessell et al. 1989, 1991), and explicitly include the effects of metallicity on the spectral shape and colors. See Worthey (1994) for details.

The distribution on the CD-ROM includes several "flavors" of model grid: (i) Five power-law IMF's plus Miller & Scalo (1979) are provided. For the power-law IMF's the lower mass cutoff was chosen so that $M/L_V = 2.5$ for globular cluster-like populations (with a reasonable accounting of stellar remnants; Worthey 1996), so output M/L values differ from the tabulation in Worthey (1994) by a constant factor plus a small perturbation caused by the fact that a small amount of low-mass starlight is missing. (ii) Also included are four schemes for how helium abundance tracks overall abundance. (iii) One model grid without helium-burning and later stages of stellar evolution is included for those interested in adding HB-, AGB-, EAGB-, PAGB-stages, or other stages of evolution by themselves. (iv) The models as tabulated in Worthey (1994) are also included unaltered.

Each model (at one age and [Fe/H]) is stored in a FITS file with ascii table extensions. One "flavor" is made of a grid of FITS files covering the range of age and [Fe/H]. A fortran program is provided that reads the data using William Pence's FITSIO routines (also included), interpolates in the model grid to arbitrary age and metallicity, and combines populations in any combination the user specifies. Multicolor color-magnitude diagrams are also available in the FITS file ascii extensions.

7. Evolutionary synthesis models: young systems

The early phase in the evolution of a stellar population ($t < 50$ Myr) is dominated by the properties of massive stars. Several models have been constructed to address issues such as the relative contributions of stellar and nebular emission, effects of stellar winds, or the properties of Wolf-Rayet stars and red supergiants. The evolutionary timescales of massive stars are often not long in comparison with the age of the population so that aspects of star formation and stellar evolution are often closely connected.

We are including three model sets which make predictions over a wide spectral range and for various properties of the population: Bressan et al. (Section 7.1), Leitherer et al. (Section 7.3), and Mas-Hesse & Cerviño (Section 7.4). The three models use three different sets of stellar evolution models, aiding the user in realizing how stellar evolution affects the synthetic spectrum (see also García-Vargas et al. (1996a). Bressan et al. have computed energy distributions for single stellar populations of different chemical composition with the latest set of Padova tracks (see Section 5). The models of Leitherer et al. are based on Maeder's (1990) multi-Z models, in combination with extended model atmospheres for Wolf-Rayet stars. The models of Mas-Hesse & Cerviño use the Geneva models described in Section 5 and give numerous properties of the stellar population, in addition to the energy distributions.

A relatively new field to explore in evolutionary synthesis work of young systems is the infrared. Dedicated modeling in this spectral region is presented by Lançon in Section 7.2. These models are particularly useful in systems with high dust content where only the infrared provides access to the underlying stellar population.

7.1. Energy Distributions for Single Stellar Populations *(Bressan, García-Vargas, & Díaz)*

We present spectral energy distributions for instantaneous star bursts formed according to a Salpeter-type IMF for ages between 1 Myr and 350 Myr. All clusters have a mass of 1×10^6 $M_\odot$. The description of the isochrones (Padova group) and the stellar atmospheres used in the modeling can be found in García-Vargas, Bressan, & Díaz (1995a).

However, in the models presented here, the IMF parameters are slightly different from those given in the mentioned paper. The spectra have been computed assuming a *standard*

Salpeter-IMF: $\alpha = 2.35$, $m_{low} = 1\ M_\odot$, $m_{up} = 100\ M_\odot$. Together with this standard set of models we also present two complementary sets of models computed with non-standard IMF's. These are models corresponding to $\alpha = 3.30$, $m_{low} = 1\ M_\odot$, $m_{up} = 100\ M_\odot$, and to $\alpha = 2.35$, $m_{low} = 1\ M_\odot$, $m_{up} = 30\ M_\odot$.

7.2. Evolution of near-IR properties of starburst regions *(Lançon)*

Starburst regions are often so heavily obscured with dust that studying them at infrared wavelengths represents a definite advantage. Near-IR spectra allow us to explore deeply embedded stellar sources and the influence of these stars on the surrounding interstellar medium, by comparisons with the predictions of evolutionary population synthesis models. The stellar energy distribution in this wavelength range is specifically sensitive to the evolving contribution of red supergiants, while the near-IR emission lines reveal ionizing stars and shocks.

The files provided present the predicted evolution of the stellar energy distribution between 1.4 and 2.5 μm for various starburst scenarios and upper mass limits of the stellar initial mass function, up to an age of 200 Myr. Selected integrated properties (total mass in stars, luminosities with and without the contribution of ionized gas, recombination lines) are also listed as functions of time. This work is the result of a collaboration with B. Rocca-Volmerange (Institut d'Astrophysique de Paris). It makes extensive use of a library of near-IR empirical stellar spectra (Lançon & Rocca-Volmerange 1992) which is continuously being further developed (contact: lancon@astro.u-strasbg.fr). Details and applications of the models can be found in Lançon (1996), Lançon, Rocca-Volmerange, & Thuan (1996), and in Lançon & Rocca-Volmerange (1996).

7.3. Spectral energy distributions for massive-star populations *(Leitherer, Heckman, & Goldader)*

We present the results of an extensive grid of evolutionary synthesis models for populations of massive stars. The parameter space has been chosen to correspond to conditions typically found in objects like giant H II regions, H II galaxies, blue compact dwarf galaxies, nuclear starbursts, and infrared luminous starburst galaxies. The models are based on the most up-to-date input physics for the theory of stellar atmospheres, stellar winds, and stellar evolution.

Observable properties of a population of stars are computed for the two limiting cases of an instantaneous burst and a constant star-formation rate over a time interval of 1 – 25 Myr, in steps of 1 Myr. Three choices of the initial mass functions are studied: a Salpeter- and a Miller-Scalo-type IMF with upper mass limits of 100 $M_\odot$, and a Salpeter IMF truncated at 30 $M_\odot$. Metallicities of 0.1 $Z_\odot$, 0.25 $Z_\odot$, $Z_\odot$, and 2 $Z_\odot$ are considered.

The output products are spectral energy distributions covering the wavelength range 50 Å to 9 μm. The files included on the CD-ROM give fluxes (i) for stars only, (ii) for nebular emission, and (iii) for gas and stars combined. The contamination of the stellar ultraviolet, optical, and near-infrared continuum by nebular emission has been discussed by Olofsson (1989), Mas-Hesse & Kunth (1991) and Leitherer & Heckman (1995). Under typical starburst conditions the nebular continuum is not negligible. Depending on the wavelength, addition of the nebular continuum leads to significantly redder or bluer broadband colors than obtained from a pure stellar continuum.

The spectral energy distributions were previously used to compute the galaxy properties published by Leitherer & Heckman (1995). The energy distributions themselves were not published in that paper, only derived quantities such as colors and magnitudes.

7.4. Evolutionary synthesis for young starbursts *(Mas-Hesse & Cerviño)*

We have computed evolutionary synthesis models for young starbursts (i.e. from 0 to 20 Myr). The models are based on evolutionary tracks from Schaerer et al (1993; and references therein) for six different metallicities ($Z_{\odot}/20$, $Z_{\odot}/5$, $Z_{\odot}/2.5$, $Z_{\odot}$, 2 $Z_{\odot}$, and $Z_{\odot}$ with enhanced mass-loss rate). They have been performed for several IMF slopes (–1, –2.35 [Salpeter], and –3) with mass limits between 2 and 120 $M_{\odot}$ and for two star-formation regimes, an instantaneous burst and for a constant star formation.

Stellar inputs are from a compilation described in Mas-Hesse & Kunth (1991) based on Kurucz and Mihalas atmosphere models, together with observational values and the atlas from Jacoby, Hunter, & Christian (1984). We have considered only solar metallicity atmosphere models for all models. The files on the CD-ROM contain all the parameters we have synthesized:

- stellar populations: O, B, A stars of V, III and I luminosity classes, WN and WC Wolf-Rayet stars, and other spectral types;
- ionizing flux and related parameters (nebular continuum, Hβ emission line strengths);
- spectral energy distributions in the range 1200 Å – 3.6 μm and the radio (~6 cm) emission;
- the ratio of the Si IV λ1400 and C IV λ1550 absorption-line equivalent widths;
- Hβ emission-line equivalent widths;
- the Wolf-Rayet bump equivalent width and its ratio to the Hβ luminosity;
- the effective temperature T_{eff}.

More details can be found in Mas-Hesse & Kunth (1991) and Cerviño & Mas-Hesse (1994). The models are currently being completed by including the effect of evolution in binary systems. Preliminary results can be found in Cerviño & Mas-Hesse (1996) and in Cerviño, Mas-Hesse, & Kunth (1996).

8. Photoionization models

8.1. Shock models for active galaxies *(Dopita & Sutherland)*

A fast, radiative shock in interstellar space is a powerful source of ionizing photons. An early attempt to investigate the effects of radiative transfer in thermally unstable cooling flows or fast radiative shocks was given by Binette, Dopita, & Tuohy (1985). Hybrid models for fast shocks with an externally imposed photoionizing field have been extensively discussed, e.g., by Contini & Viegas-Aldrovandi (1987, and references therein), and these have been extensively applied to the interpretation of narrow emission-line regions of active galaxies.

An accurate treatment of the internal radiative transfer in fast shocks was accomplished in the code MAPPINGS II (Sutherland & Dopita 1993). Sutherland, Bicknell, & Dopita (1993) applied this to the interpretation of the optical spectra of the filaments associated with the radio jet of Cen A.

The files given in the present contribution are the models used in the papers by Dopita & Sutherland (1995, 1996) where full details can be had. There are a two points that must be emphasized if these models are to be used successfully.

First, in order to compute the spectrum of a fast shock, we have to compute two contributions: (i) the spectrum produced by the cooling/recombination region of the shock itself; (ii) the spectrum produced in the photoionized precursor H II region, which for shock velocities greater than 200 km s^{-1} can be treated as an equilibrium H II region.

Second, the parameters which determine the spectrum are shock velocity, pre-shock density, and magnetic pressure in the pre-shock gas. These models presented here run from 150 – 500 km s^{-1}. All models are plane-parallel, steady flow. The pre-shock hydrogen density for all models is 1.0 cm^{-3}. This density is low enough that all models are in the low density limit. In this case, cooling lengths, timescales etc. scale as (1/density) and luminosity scales directly as density. These scaling factors can be used to estimate other shock structures up to a density of about 10 cm^{-3} for magnetic parameter < 1.0, and up to about 100 cm^{-3} for magnetic parameter > 1.0. The magnetic parameter is $(\mathrm{B}/\mu\mathrm{Gauss})/(\mathrm{n}/1.0\ \mathrm{cm}^{-3})^{0.5}$. This determines the degree of magnetic pressure support in the recombination region of the shock, where the downstream photons produced in the hot plasma are absorbed. This makes a *big* difference to the output spectrum.

In the use of these models, the user should be aware that the cooling is thermally unstable, and that *real* shocks have a complex 3-d structure with condensations. This will help to make the shock structures "leaky" to the photon field in the downstream direction. The line intensities of species such as [N I] and [O I] are almost certainly overestimated in the models, and the spectrum will also tend to fluctuate in time, which is not accounted for in these steady-flow models. See Dopita & Sutherland (1995, 1996) for a more detailed discussion of these effects.

8.2. Predicted emission lines from giant H II regions *(García-Vargas, Bressan, & Díaz)*

We have computed theoretical models of the emission-line spectra of giant extragalactic H II regions (GEHR) in which a single star cluster is assumed to be responsible for the ionization. Ionizing clusters, of different masses and metallicities, were constructed assuming that they formed in a single burst and with a Salpeter initial mass function. Their evolution was then followed in detail up to an age of 5.4 Myr after which they lack the high energy photons needed to keep the regions ionized.

The integrated spectral energy distribution of every cluster has been computed for a set of discrete ages representative of relevant phases of their evolution and have been processed by the photoionization code CLOUDY, in order to obtain the corresponding emission-line spectra of the ionized gas at optical and infrared wavelengths.

A wide range of initial compositions spanning from about 1/20 ($Z = 0.001$) to 2.5 $Z_{\odot}$ ($Z = 0.05$) and total masses between about $1 - 6 \times 10^4$ $M_{\odot}$ have been considered. Gas and stars are assumed to have the same metallicity and this has been taken into account both in the stellar evolution and atmosphere models and in the nebular gas producing a consistent set of models. In this contribution we give the synthetic emission-line spectra of the ionized regions which are discussed in detail in García-Vargas, Bressan, & Díaz (1995a,b).

8.3. FIR emission-line models for star-forming regions *(Iglesias, García-Vargas, & Bressan)*

We calculated a grid of photoionization models which can be suitable to interpret the coming ISO observations. We also include the strongest optical emission lines. We present the synthetic emission line spectra, emphasizing the FIR emission lines' importance in high metallicity environments where the cooling of the gas is mainly driving through them.

We have assumed a shape for the ionizing spectrum, and it has been processed by the photoionization code CLOUDY, under certain conditions (ionization parameter, electron density and metallicity), in order to obtain a grid of computed emission-line spectra of the ionized gas at optical and infrared wavelengths.

The assumed ionizing continuum has a power-law-type spectrum (slope of –1.5, –2.0, –2.5), or an instantaneous burst (ages: 2.0, 3.5, 4.5, 5.0 Myr and IMF parameters: $\alpha = 2.35$, $m_{low} = 1$ $M_{\odot}$, $m_{up} = 100$ $M_{\odot}$). A more complicated way of star-formation, including models with some SFR and other with a certain burst duration, as well as a discussion of the dust effect will be published in a forthcoming paper. Densities are 100, 500, 1000, and 10000 cm^{-3}. Ionization parameters are taken in the range $10^{-1.5} - 10^{-4}$ (step 0.5 in log u), and metallicities 0.5 $Z_{\odot}$, $Z_{\odot}$, and 2.5 $Z_{\odot}$.

The selected optical emission lines are: [O II]3727 (3726+3729), [O III]4363, [O III]5007, [O I]6300, [S II]6716, [S II]6731, and [S III]9532. The listed infrared lines are: [S IV]10.5, [Ne II]12.8 , [S III]19, [O IV]25.9, [O III]51.8, [N III]57, [O I]63.2, [O III]88.3, [N II]121.9, [O I]145.5 and [C II]157.7.

8.4. Grids of photoionization models for single-star H II regions and for evolving starbursts *(Stasińska)*

We present three grids of photoionization models using the code PHOTO (Stasińska 1990) with atomic data updated as in Stasińska & Leitherer (1996). The ionizing fluxes are provided by the *CoStar* model atmospheres of Schaerer et al. (1996a,b) and Schaerer (1996), by the Kurucz (1992) model atmospheres, and by the stellar population synthesis models for evolving starbursts computed by Leitherer & Heckman (1995) and used in Stasińska & Leitherer (1996). The grids cover a wide parameter space in metallicity and ionizing conditions. They provide the intensities of about 100 lines in the optical, UV and IR, together with ionization fractions for the most important ions, as well as a few other parameters useful for diagnostics of H II regions.

Financial support for the production of the CD-ROM was provided by Space Telescope Science Institute through a grant from the Director's Discretionary Research Fund.

REFERENCES

Alloin, D. 1996, in From Stars to Galaxies: The Impact of Stellar Physics on Galaxy Evolution, ed. C. Leitherer, U. Fritze-von Alvensleben, & J. Huchra, ASP Conf. Series, Vol. 98, 115

Bernasconi, P. A. 1996, A&AS, in preparation

Bessell, M. S., & Brett, J. M. 1988, PASP, 100, 1134

Bessell, M. S., Brett, J. M., Scholz, M., & Wood, P. R. 1989, A&AS, 77, 1

——. 1991, A&AS, 89, 335

Bica, E. 1988, A&A, 195, 76

Bica, E., & Alloin, D. 1986a, A&A, 162, 21

——. 1986b, A&AS, 66, 171

——. 1987a, A&A, 186, 49

——. 1987b A&AS, 70, 281

Bica, E., Alloin, D., & Schmidt, A. 1990, A&A, 228, 23

Bica, E., Alloin, D., & Schmitt, H. 1994, A&A, 283, 805

Bica, E., Bonatto, C., Pastoriza, M. G., & Alloin, D. 1996, A&A, submitted

Binette, L., Dopita, M. A., & Tuohy, I. R. 1985, ApJ, 297, 476

Bonatto, C., Bica, E., & Alloin, D. 1995, A&AS, 112, 71

Bonatto, C., Bica, E., Pastoriza, M. G., & Alloin, D. 1996, A&AS, in press

Bruzual A., G., & Charlot, S. 1996, ApJ, in preparation

Castor, J. I., Abbott, D. C., & Klein, R. I., 1975, ApJ, 195, 157

Cerviño, M. & Mas-Hesse, J. M. 1994, A&A, 284, 749

——. 1996, in From Stars to Galaxies: The Impact of Stellar Physics on Galaxy Evolution, ed. C. Leitherer, U. Fritze-von Alvensleben, & J. Huchra, ASP Conf. Series, Vol. 98, 218

Cerviño, M., Mas-Hesse, J. M., & Kunth, D., 1996, in preparation

Charbonnel, C. 1996, in preparation

Charbonnel, C., Meynet, G., Maeder, A., & Schaerer, D. 1996, A&AS, in press (CMMS)

Charbonnel, C., Meynet, G., Maeder, A., Schaller, G., & Schaerer, D. 1993, A&AS, 101, 415 (CMMSS)

Charlot, S., Worthey, G., & Bressan, A. 1996, ApJ, 457, 625

Chavez, M., Malagnini, M. L., & Morossi, C. 1996b, ApJ, submitted

Chavez, M., Malagnini, M. L., Morossi, C., & Buzzoni, A. 1996a, in From Stars to Galaxies: The Impact of Stellar Physics on Galaxy Evolution, ed. C. Leitherer, U. Fritze-von Alvensleben, & J. Huchra, ASP Conf. Series, Vol. 98, 100

Chiosi, C., Bertelli, G., & Bressan, A. 1992, ARAA, 30, 235

Chiosi, C., & Maeder, A. 1986, ARAA, 24, 329

Conti, P. S. 1988, in O Stars and WR Stars, ed. P. S. Conti & A. B. Underhill (NASA SP-497), 81

Contini, M., & Viegas-Aldrovandi, S. M. 1987, A&A, 185, 39

Dallier, R., Boisson, C., & Joly, M. 1996, A&AS, in press

de Jager, C., Nieuwenhuijzen, H., & van der Hucht, K. A. 1988, A&AS, 72, 259

Delisle, S., & Hardy, E. 1996, in From Stars to Galaxies: The Impact of Stellar Physics on Galaxy Evolution, ed. C. Leitherer, U. Fritze-von Alvensleben, & J. Huchra, ASP Conf. Series, Vol. 98, 335

Díaz, A. I., Terlevich, E., & Terlevich, R. 1989, MNRAS, 239, 325

Dopita, M. A., & Sutherland, R. S. 1995, ApJ, 455, 468

——. 1996, ApJS, 102, 161

Dorman, B., Rood, R. T., & O'Connell, R. W. 1993, ApJ, 419, 596

——. 1995, ApJ, 442, 105

Fanelli, M. N., O'Connell, R. W., Burstein, D., & Wu, C.-C. 1992, ApJS, 82, 197

Fioc, M., & Rocca-Volmerange, B. 1996, A&A, submitted

García-Vargas, M. L., Bressan, A., & Díaz, A. I. 1995a, A&AS, 112, 13

García-Vargas, M. L., Bressan, A., & Díaz, A. I. 1995b, A&AS, 112, 35

García-Vargas, M. L., Leitherer, C., & Bressan, A. 1996a, in preparation

García-Vargas, M. L., Mollá, M. L., & Bressan, A., 1996b, A&A, submitted.

Howarth, I. D., & Prinja, R. K. 1989, ApJS, 69, 527

Huchra, J. P., Brodie, J. P., Caldwell, N., Christian, C., & Schommer R. 1996, ApJS, 102, 29

Iglesias, C. A., & Rogers, F. J. 1993, ApJ, 412, 752

Iglesias, C. A., Rogers, F. J., & Wilson, B. G. 1992, ApJ, 397, 717

Jablonka, P., Alloin, D., & Bica, E. 1992, A&A, 260, 97

Jacoby, G. H., Hunter, D. A., & Christian, C. A. 1984, ApJS, 56, 257

Kudritzki, R. P., Pauldrach, A., Puls, J., & Abbott, D. C. 1989, A&A, 219, 205

Kudritzki, R. P., Pauldrach, A., Puls, J., & Voels, S. R. 1991, in IAU Symp. 148, The Magellanic Clouds, ed. R. Haynes & D. Milne (Dordrecht: Kluwer), 279

Kurucz, R. L. 1991, in Stellar Atmospheres: Beyond Classical Models, ed. L. Crivellari, I. Hubeny, & D. G. Hummer (Dordrecht: Kluwer), 441

——. 1992a, in IAU Symp. 149, The Stellar Population of Galaxies, ed. B. Barbuy & A. Renzini (Dordrecht: Kluwer), 225

——. 1992b, private communication

——. 1993, ATLAS9 Stellar Atmosphere Programs and 2 km s^{-1} grid (Kurucz CD-ROM No. 13)

Lançon, A., 1996, in From Stars to Galaxies: The Impact of Stellar Physics on Galaxy Evolution, ed. C. Leitherer, U. Fritze-von Alvensleben, & J. Huchra, ASP Conf. Series, Vol. 98, 123

Lançon, A., & Rocca-Volmerange, B. 1992, A&AS, 96, 593

Lançon, A., & Rocca-Volmerange, B. 1996, A&A, submitted

Lançon, A., Rocca-Volmerange, B., & Thuan, T. X. 1996, A&AS, 115, 253

Langer, N. 1989, A&A, 220, 135

Leitherer, C., Fritze-von Alvensleben, U., & Huchra, J. 1996, From Stars to Galaxies: The Impact of Stellar Physics on Galaxy Evolution, ASP Conf. Series, Vol. 98

Leitherer, C., & Heckman T. M. 1995, ApJS, 96, 9

Leitherer, C., Robert, C., & Heckman, T. M. 1995, ApJS, 99, 173

Maeder, A. 1990, A&AS, 84, 139

Mas-Hesse, J. M., & Kunth, D 1991, A&AS, 88, 317

Meynet, G., Maeder, A., Schaller, G., Schaerer, D., & Charbonnel C. 1994, A&AS, 103, 97 (MMSSC)

Miller, G. E., & Scalo J. M. 1979, ApJS, 41, 573

Mowlavi, N., et al. 1996, A&AS, in preparation

O'Connell, R. W. 1973, AJ, 78, 1074

Ødegaard, K. J. R. 1996a, in Planetary Nebulae with WR Type Nuclei, Ap&SS, in press

Ødegaard, K. J. R. 1996b, in From Stars to Galaxies: The Impact of Stellar Physics on Galaxy Evolution, ed. C. Leitherer, U. Fritze-von Alvensleben, & J. Huchra, ASP Conf. Series, Vol. 98, 156

Olofsson, K. 1989, A&AS, 80, 317

——. 1996, in From Stars to Galaxies: The Impact of Stellar Physics on Galaxy Evolution, ed. C. Leitherer, U. Fritze-von Alvensleben, & J. Huchra, ASP Conf. Series, Vol. 98, 77

Robert, C., Leitherer, C., & Heckman, T. M. 1993, ApJ, 418, 749

Rogers, F. J., & Iglesias, C. A. 1992, ApJ, 401, 361

Schaerer, D. 1996, A&A, in preparation

Schaerer, D., & Bernasconi, P. A. 1996, A&A, in preparation

Schaerer, D., Charbonnel, C., Meynet, G., Maeder, A., & Schaller, G. 1993, A&AS, 102, 339 (SCMMS)

Schaerer, D., de Koter, A., Schmutz, W., & Maeder, A. 1996a, A&A, in press

——. 1996b, A&A, in press

Schaerer, D., Meynet, G., Maeder, A., & Schaller, G. 1993, A&AS, 98, 523 (SMMS)

Schaller, G., Schaerer, D., Meynet, G., & Maeder A. 1992, A&AS, 96, 269 (SSMM)

Scheiner, J. 1899, ApJ, 9, 149

Schmutz, W. 1996, in From Stars to Galaxies: The Impact of Stellar Physics on Galaxy Evolution, ed. C. Leitherer, U. Fritze-von Alvensleben, & J. Huchra, ASP Conf. Series, Vol. 98, 92

Schmutz, W., Leitherer, C., & Gruenwald, R., 1992, PASP, 104, 1164

Serote, M., Boisson, C., & Joly, M. 1996, A&AS, in press

Silva, D. R., & Cornell, M. E. 1992, ApJS, 81, 865

St.-Louis, N. 1990, Ph. D. thesis, Univ. College London

Stasińska, G. 1990, A&AS, 83, 501,

Stasińska, G., & Leitherer, C. 1996, ApJS, in press

Sutherland, R. S., & Dopita, M. A. 1993, ApJS, 88, 253

Sutherland, R. S., Bicknell, G. V., & Dopita, M. A. 1993, ApJ, 414, 510

VandenBerg, D. A. 1985, ApJS, 58, 561

VandenBerg, D. A., & Bell, R. A. 1985, ApJS, 58, 561

VandenBerg, D. A., & Laskarides, P. G. 1987, ApJS, 64, 103

Vazdekis, A., Casuso, E., Peletier, R., & Beckman, J. E. 1996, ApJ, submitted

Walborn, N. R., Nichols-Bohlin, J., & Panek, R. J. 1985, IUE Atlas of O-Type Spectra From 1200 to 1900 Å, NASA Ref. Pub. 1155

Walborn, N. R., Parker, J. Wm., & Nichols, J. S. 1995, IUE Atlas of B-Type Spectra From 1200 to 1900 Å, NASA Ref. Pub. 1363

Worthey, G. 1994, ApJS, 95, 107

——. 1996, in preparation

This manuscript was prepared with the AAS LaTeX macros v4.0.

Table 1: Overview of the database

Dataset	Category[a]	Authors	Section	Reference
Stellar libraries (optical + IR)	emp	Boisson et al.	2.1	Dallier et al. (1996), Serote et al. (1996)
UV group library	emp	Fanelli et al.	2.2	Fanelli et al. (1992)
Coudé feed library	emp	Jones	2.3	this paper
Optical group library	emp	O'Connell	2.4	O'Connell (1973)
IUE library of O- and WR-stars	emp	Robert et al.	2.5	Robert et al. (1993)
IUE atlas of O-type spectra	emp	Walborn et al.	2.6	Walborn et al. (1985)
IUE atlas of B-type spectra	emp	Walborn et al.	2.7	Walborn et al. (1995)
Mg and Fe spectral indices	theor	Chavez et al.	3.1	Chavez et al. (1996b)
Spectral indices for SSP's	theor	Chiosi & Tantalo	3.2	TBD
Calcium triplet synthesis	theor	García-Vargas et al.	3.3	García-Vargas et al. (1996)
Energy distributions of cool stars	theor	Lejeune	3.4	TBD
Energy distributions of WR stars	theor	Schmutz	3.5	Schmutz (1996)
Cluster and galaxy templates	clust	Bica et al.	4.1	this paper
M32, NGC185, and NGC205	clust	Hardy & Delisle	4.2	Delisle & Hardy (1996)
Narrow band indices	clust	Huchra et al.	4.3	Huchra et al. (1996)
Padova library of evolution models	tracks	Chiosi & Tantalo	5.1	TBD
Padove isochrones and SSP models	tracks	Chiosi & Tantalo	5.2	TBD
Geneva library of evolution models	tracks	Meynet & Maeder	5.3	SSMM,SMMS,CMMSS,SCMMS,MMSSC,CMMS
Evolution and nucleosynthesis	tracks	Ødegaard	5.4	Ødegaard (1996a,b)
CoStar models	tracks	Schaerer	5.5	Schaerer et al. (1995a,b)
Galaxy spectral evolution	syn/o	Bruzual & Charlot	6.1	TBD
Spectral evolution of SSP's	syn/o	Chiosi & Tantalo	6.2	TBD
Models of elliptical galaxies	syn/o	Chiosi & Tantalo	6.3	TBD
UV spectra for old populations	syn/o	Dorman	6.4	Dorman et al. (1993; 1995)
Spectral evolution (UV to IR)	syn/o	Fioc & Rocca-Volmerange	6.5	Rocca-Volmerange et al. (in prep)
Grid of galaxy spectra	syn/o	Fritze-v. Alvensleben	6.6	TBD
Grid of evolutionary spectra	syn/o	Traat	6.7	TBD
A library for old systems	syn/o	Vazdekis et al.	6.8	Vazdekis et al. (1996)
Models for early-type galaxies	syn/o	Worthey	6.9	Worthey (1994)
Energy distributions for SSP's	syn/y	Bressan et al.	7.1	García-Vargas et al. (1995a)
Near-IR properties of starbursts	syn/y	Lançon	7.2	Lançon (1996)
Energy distributions for hot stars	syn/y	Leitherer et al.	7.3	Leitherer & Heckman (1995)
Synthesis of young starbursts	syn/y	Mas-Hesse & Cerviño	7.4	Cerviño & Mas-Hesse (1994)
Shock models for active galaxies	photo	Dopita & Sutherland	8.1	Dopita & Sutherland (1995, 1996)
Emission lines from GEHR	photo	García-Vargas et al.	8.2	García-Vargas et al. (1995a,b)
FIR emission-line models	photo	Iglesias et al.	8.3	TBD
Models for HII regions and starbursts	photo	Stasińska	8.4	TBD, Stasińska & Leitherer (1996)

[a] emp – empirical stellar library; theor – theoretical stellar library; clust – empirical cluster and galaxy library; tracks – stellar evolution models; syn/o – evolutionary synthesis of old systems; syn/y – evolutionary synthesis of young systems; photo – photoionization models

Table 2: Definitions for line indices and colors of Huchra et al. (1996)[b]

Index	C1	I	C2
Suntzeff Indices			
CA	3650.00–3780.0	3910.00–4020.00	4020.00–4130.00
HK	—	3910.00–4020.00	4020.00–4130.00
CN	—	3850.00–3878.00	3896.00–3912.00
Faber and Burstein Indices			
CNR	4082.00–4118.50	4144.00–4177.50	4246.00–4284.75
CH = G-band	4268.25–4283.25	4283.25–4317.00	4320.75–4335.75
Hβ	4829.50–4848.25	4849.50–4877.00	4878.25–4892.00
Mg H	4897.00–4958.25	5071.00–5134.75	5303.00–5366.75
Mg_2	4897.00–4958.25	5156.00–5197.25	5303.00–5366.75
Mg b	5144.50–5162.00	5162.00–5193.25	5193.25–5207.00
Fe 5270 = FE52	5235.50–5249.25	5248.00–5286.75	5288.00–5319.25
Fe 5335	5307.25–5317.25	5314.75–5353.50	5356.00–5364.75
Na I	5863.00–5876.75	5879.25–5910.50	5924.50–5949.25
TiO_1	5819.00–5850.25	5939.00–5995.25	6041.00–6104.75
TiO_2	6069.00–6142.75	6192.00–6273.25	6375.00–6416.25
Brodie and Hanes Indices			
CNB	3785.00–3810.00	3810.00–3910.00	3910.00–3925.00
H + K	3910.00–3925.00	3925.00–3995.00	3995.00–4010.00
Ca I	4200.00–4215.00	4215.00–4245.00	4245.00–4260.00
G	4275.00–4285.00	4285.00–4315.00	4315.00–4325.00
H_β	4800.00–4830.00	4830.00–4890.00	4890.00–4920.00
Mg G	5125.00–5150.00	5150.00–5195.00	5195.00–5220.00
Mg H	4740.00–4940.00	4940.00–5350.00	5350.00–5550.00
FC	5225.00–5250.00	5250.00–5280.00	5280.00–5305.00
Na D	5835.00–5865.00	5865.00–5920.00	5920.00–5950.00
Delta	3800.00–4000.00	4000.00–4200.00	—

[b] C1 + C2 are the continuum bandpasses on either side of I the index bandpass